



Systematic Errors in Dimensional X-ray Computed Tomography

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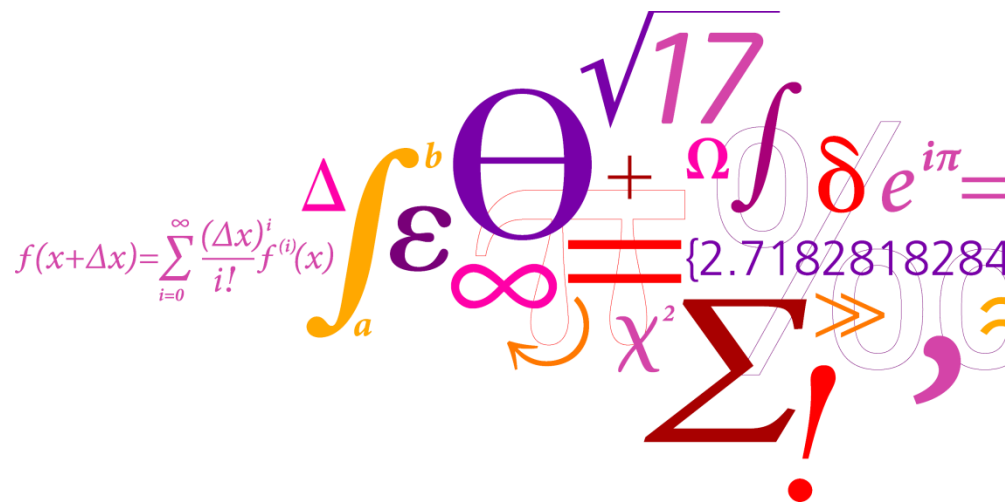
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Systematic Errors in Dimensional X-ray Computed Tomography

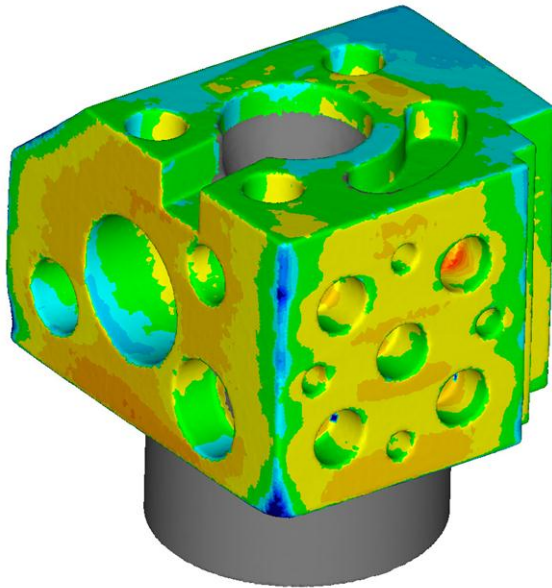
Jochen Hiller

Måletekniske dage
Teknologisk Institut
31.05.2012

DTU Mekanik
Institut for Mekanisk Teknologi

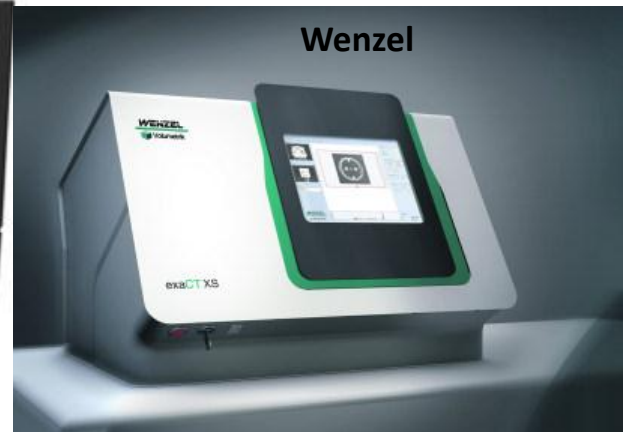


Overview



- Industrial X-ray CT today
- Dimensional CT as a key technology in production metrology
- Errors sources and a good practice in CT scanning
- Conclusions and future works

Industrial X-ray CT today

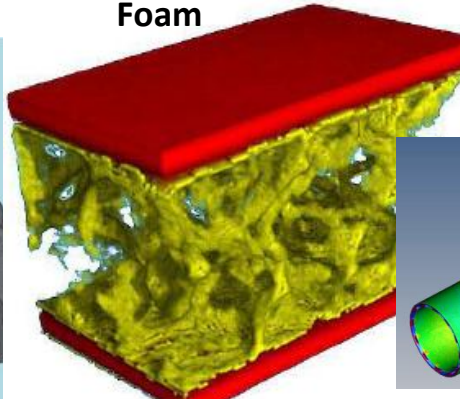


Industrial X-ray CT today

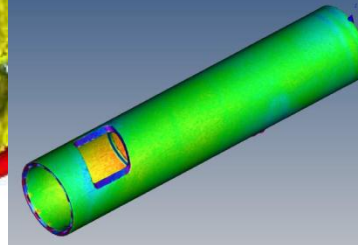
Aluminum casting



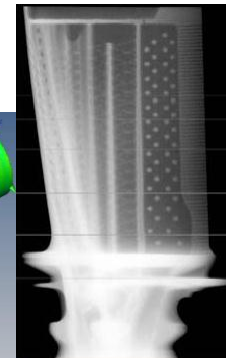
Foam



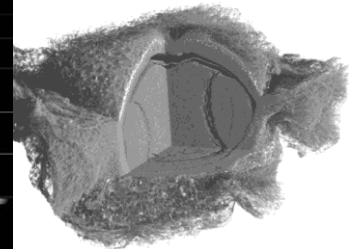
Insulin pen



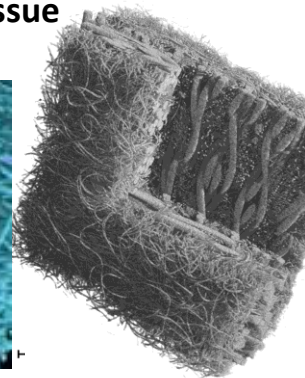
Turbine plate



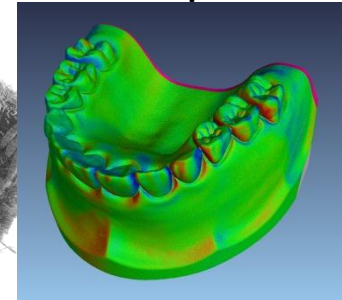
Seed



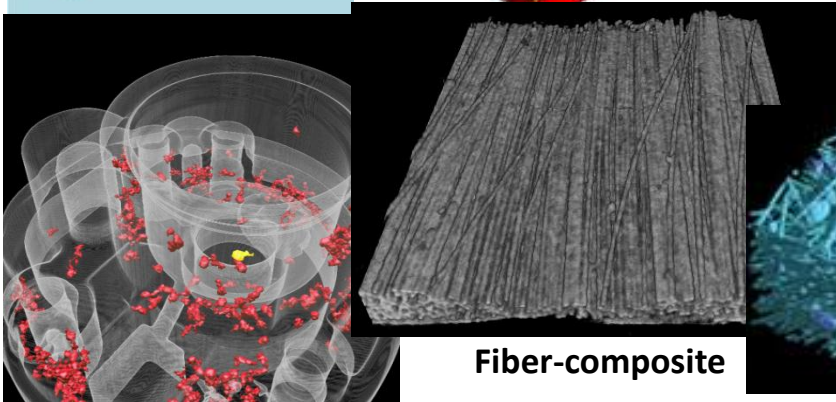
Tissue



Dental impression

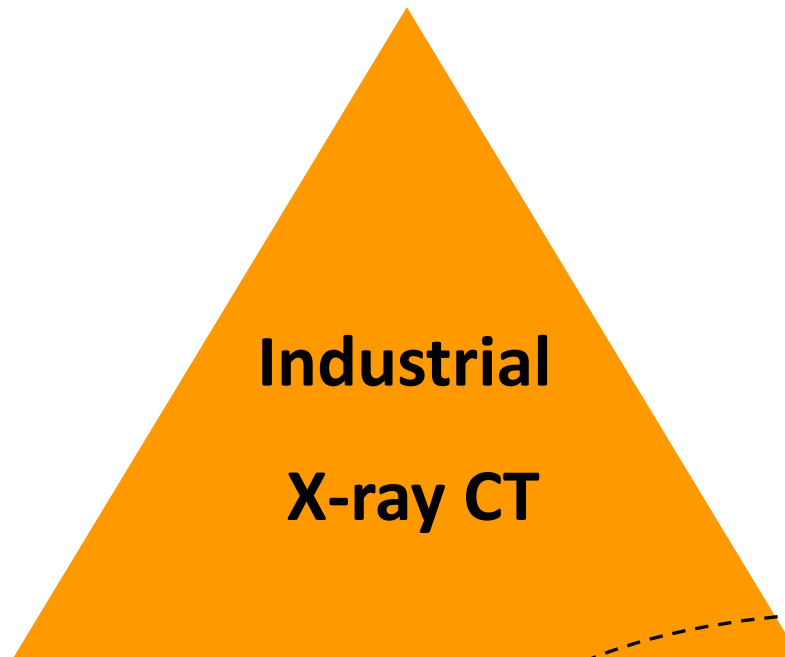


Fiber-composite

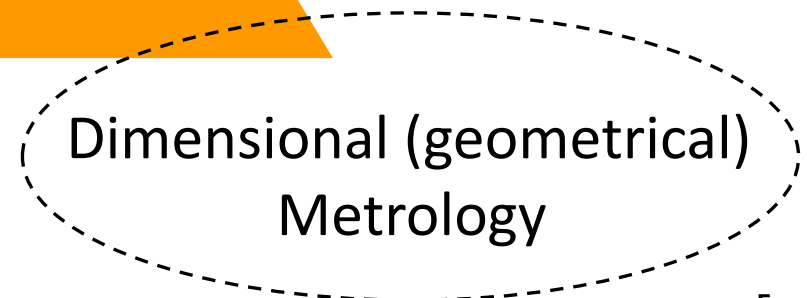


Industrial X-ray CT today

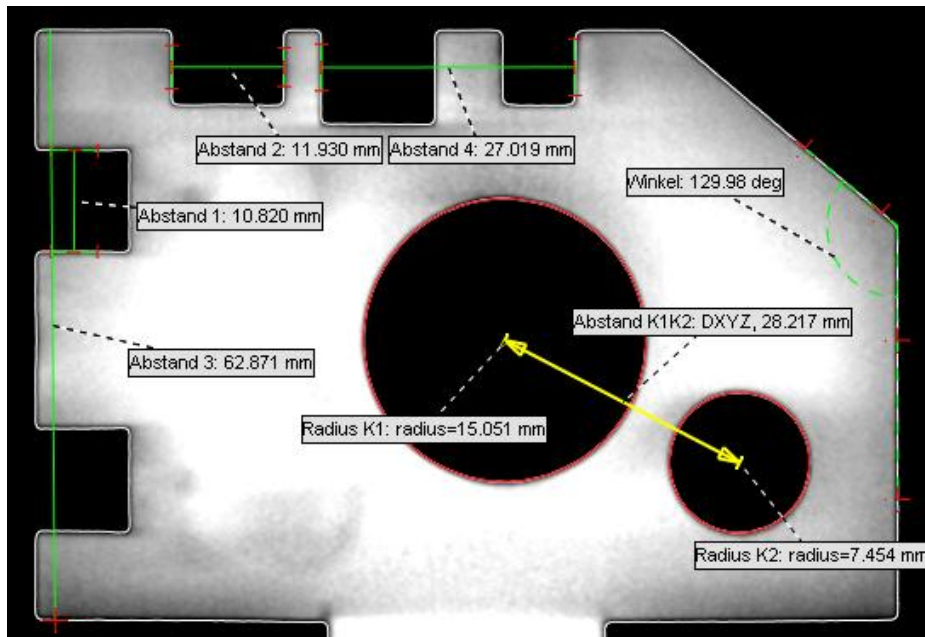
Material Testing



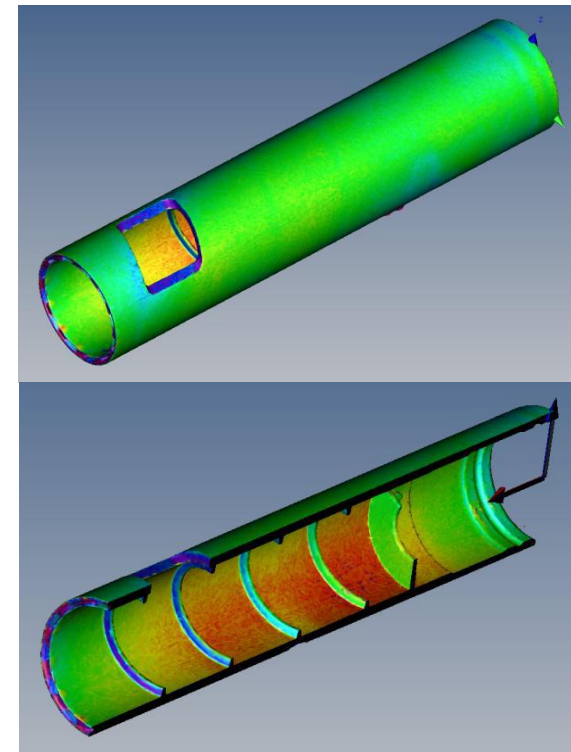
Material Analysis



Dimensional CT as a key technology in production metrology

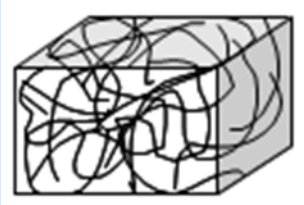
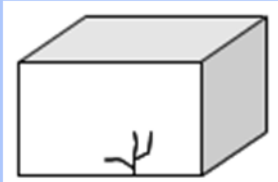
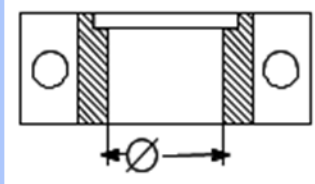


Measurement of size, form, and position



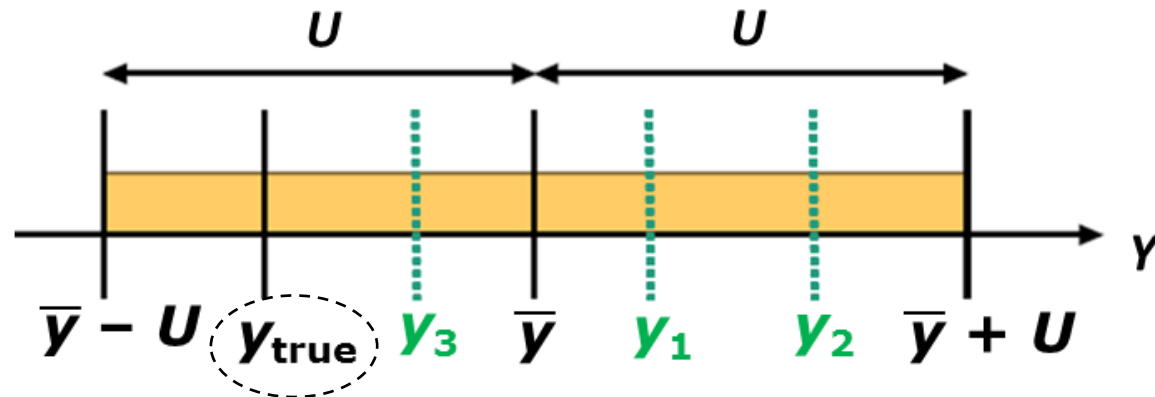
CAD/CT comparison

Dimensional CT as a key technology in production metrology

Application	Material Analysis	Material Testing	Dimensional Metrology
Symbol			
Performance Parameter	Structural Resolution	Failure Detectibility	Measurement Uncertainty

Dimensional CT as a key technology in production metrology

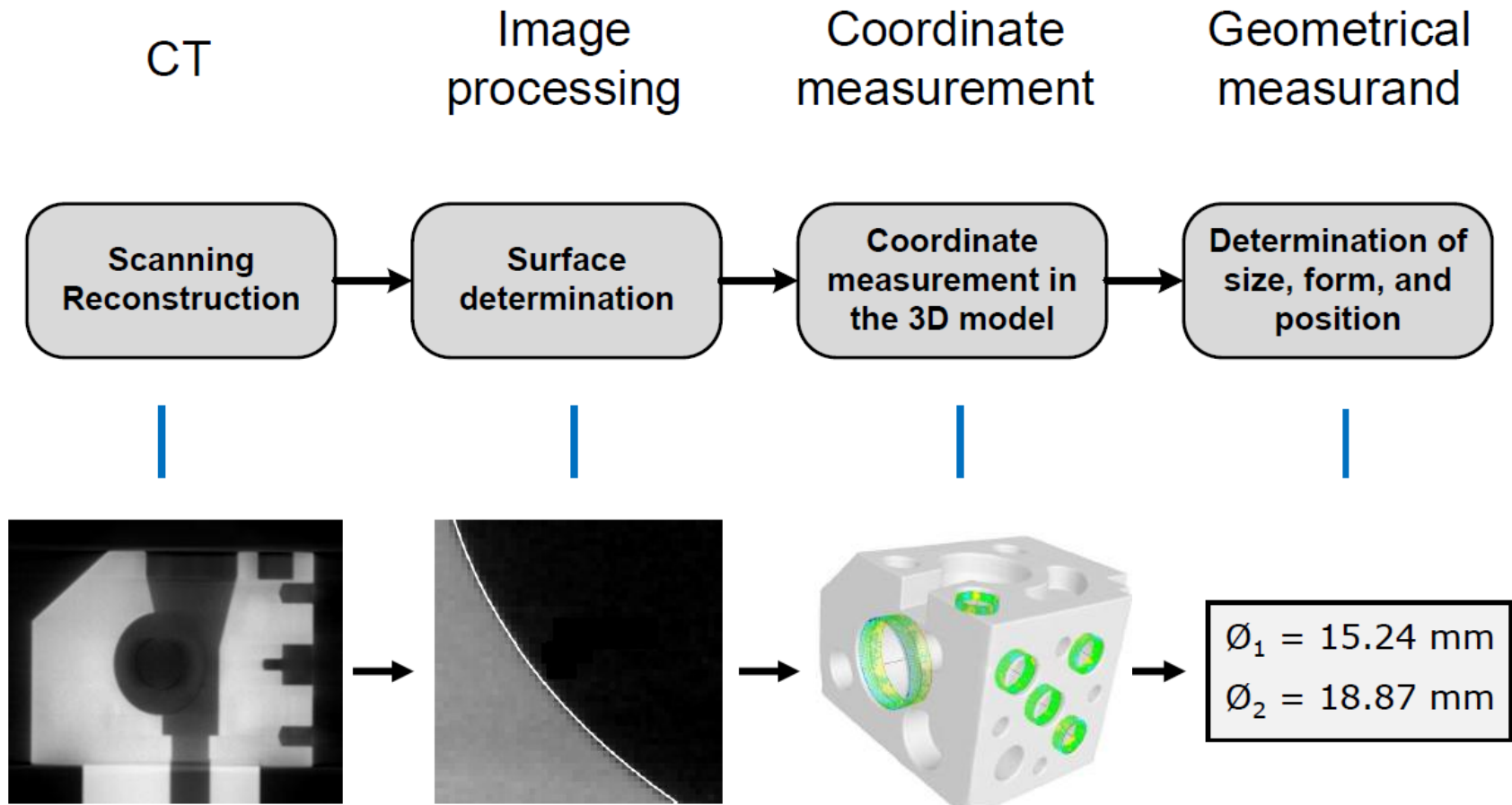
Measurement uncertainty U :



- We will never know the *true* value of a measurement
- Measurement results must be repeatable and reproducible
- What about systematic (effects) errors?

Should be corrected!

Errors sources and good practice in CT scanning

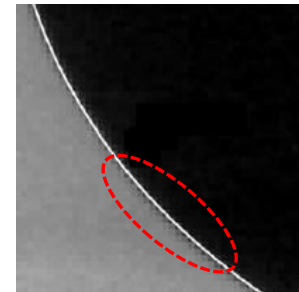


Errors sources and good practice in CT scanning

What are sources of systematic errors?

- Image artefacts
- Scaling (voxel size) error
- CT system limits (image blurring, noise)

**Segmentation and surface
determination errors**

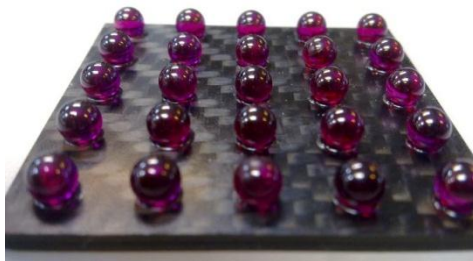


- Metrological data evaluation strategy

Errors sources and good practice in CT scanning

Can we use calibration artefacts?

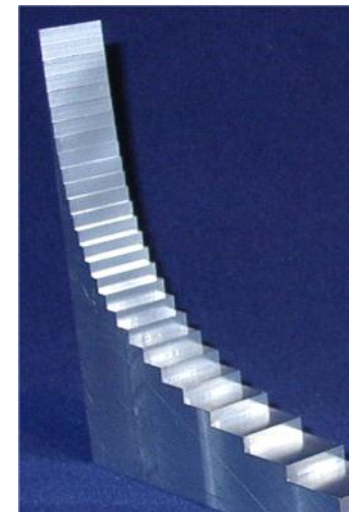
Only for the compensation of effects linked to geometrical scanner misalignment or beam-hardening artefacts



Ball-plate



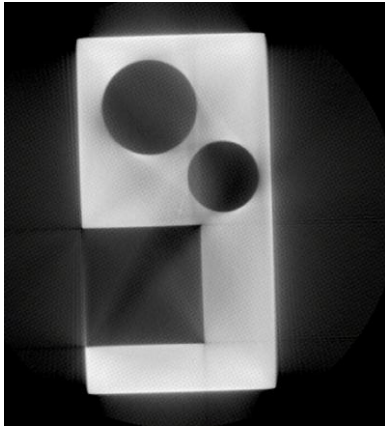
Ball-bar



Step-wedge

- Calibrated masterpieces
- Systematic scanning and evaluation planning to avoid high systematic errors (blunder)

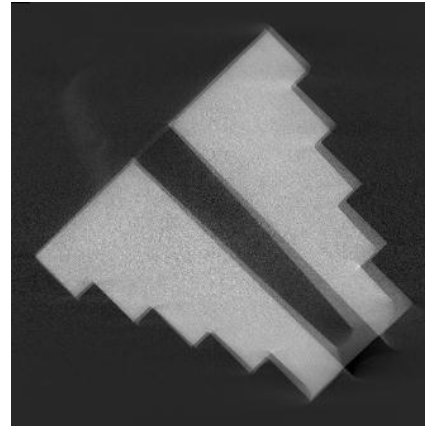
Errors sources and good practice in CT scanning



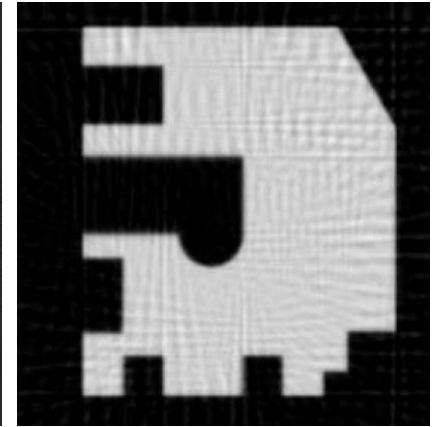
Beam-hardening



Cone-beam



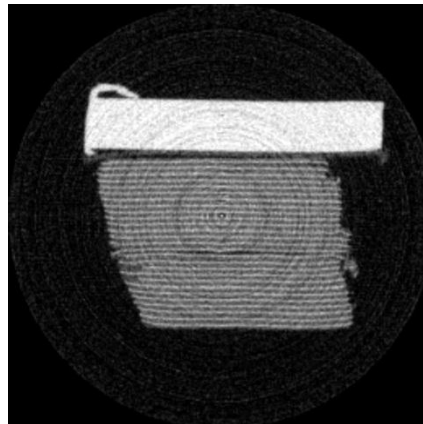
Misalignment



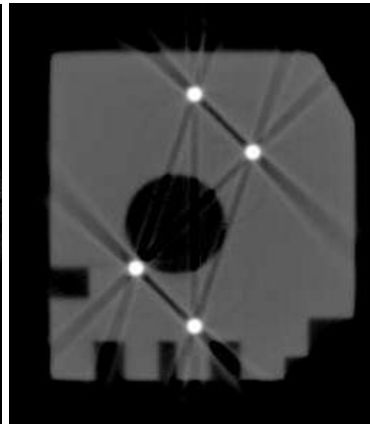
Undersampling



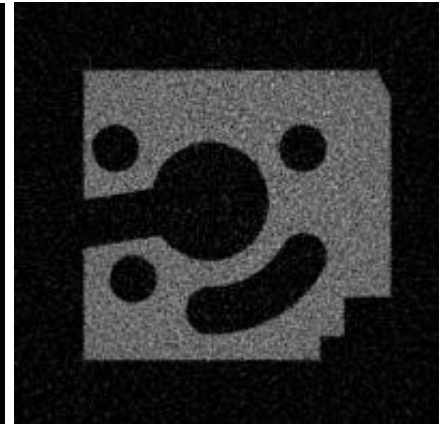
Truncation



Ring artifacts



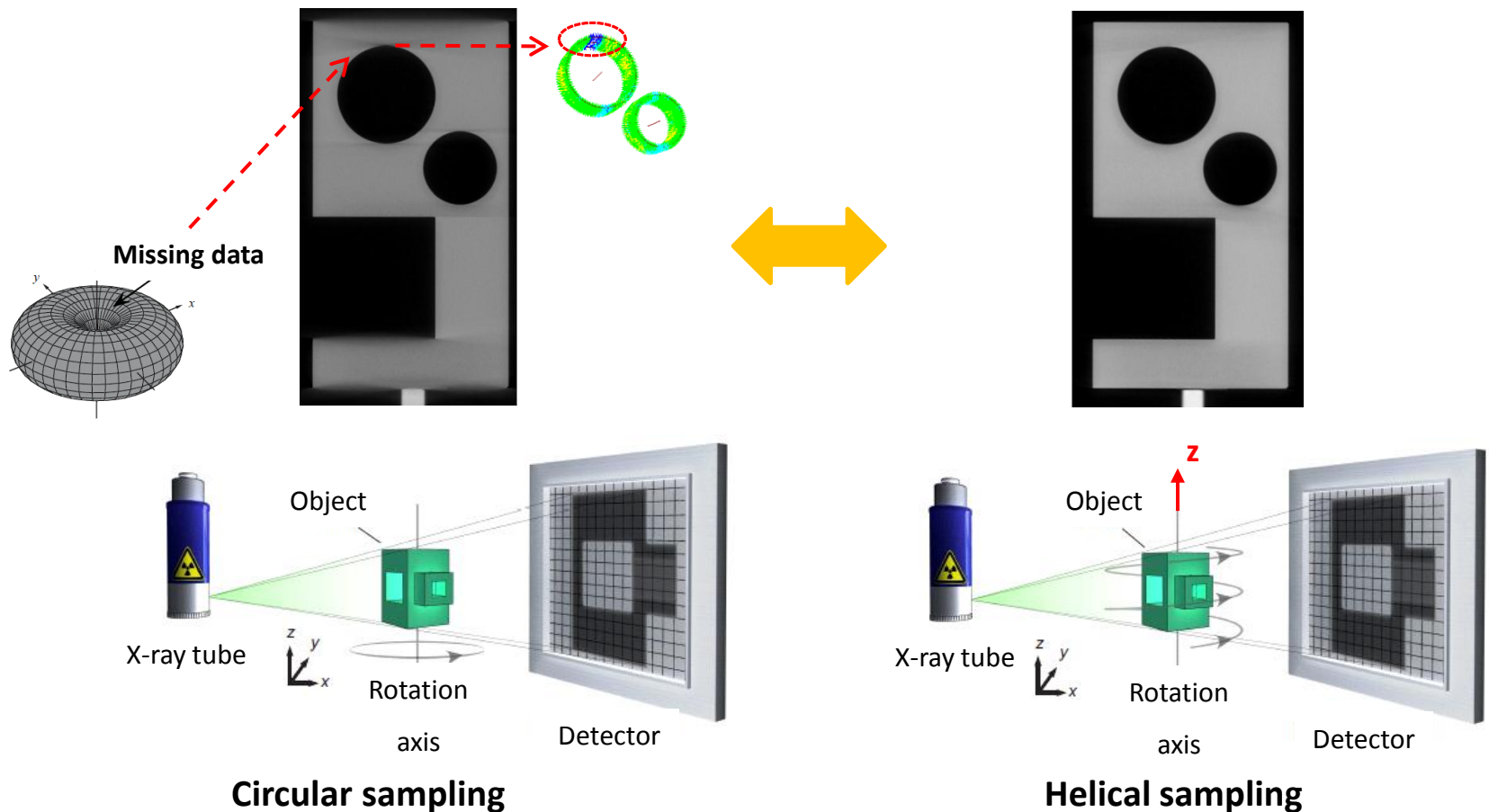
Metal artifacts



Noise artifacts

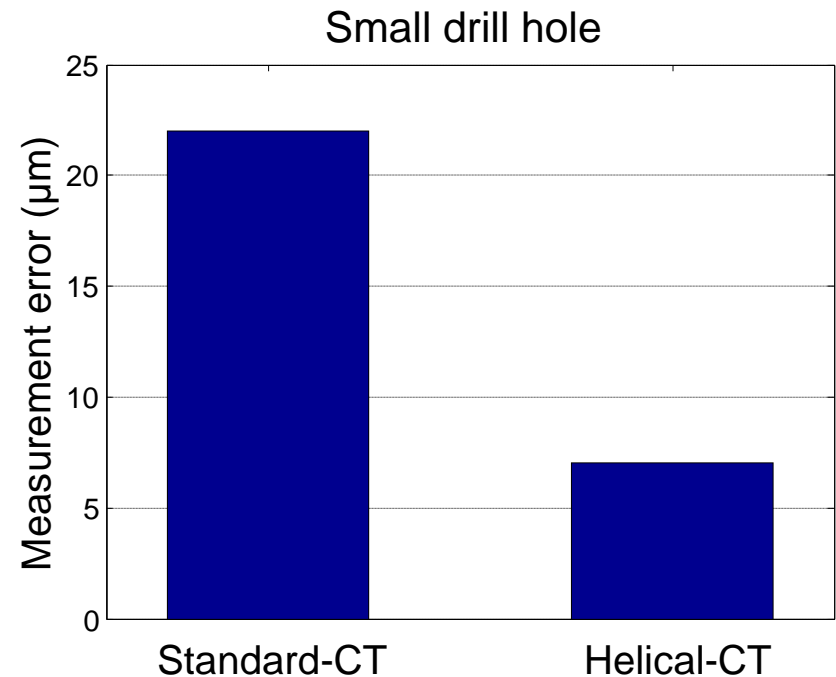
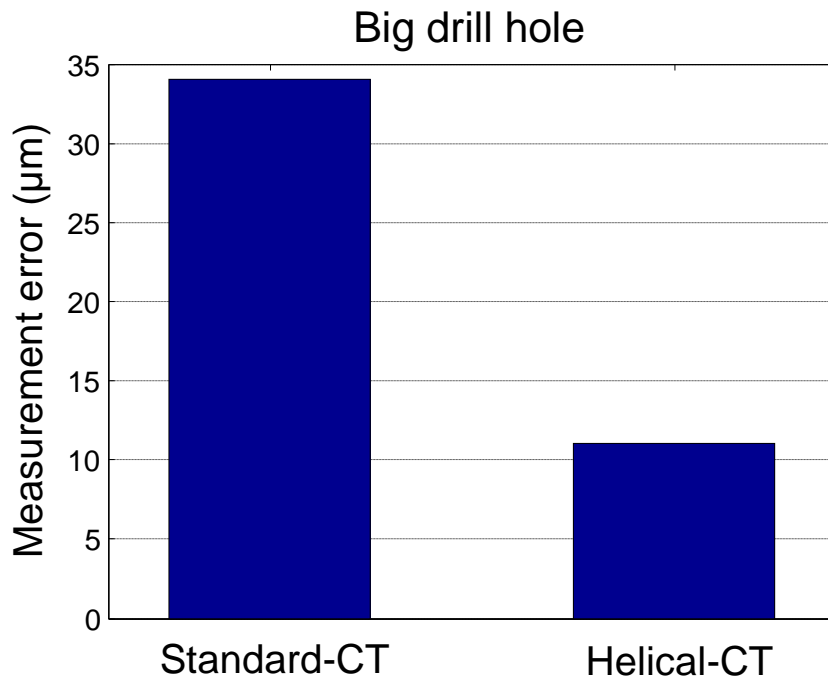
Errors sources and good practice in CT scanning

Cone-beam artefacts:



Errors sources and good practice in CT scanning

Standard vs.helical CT:

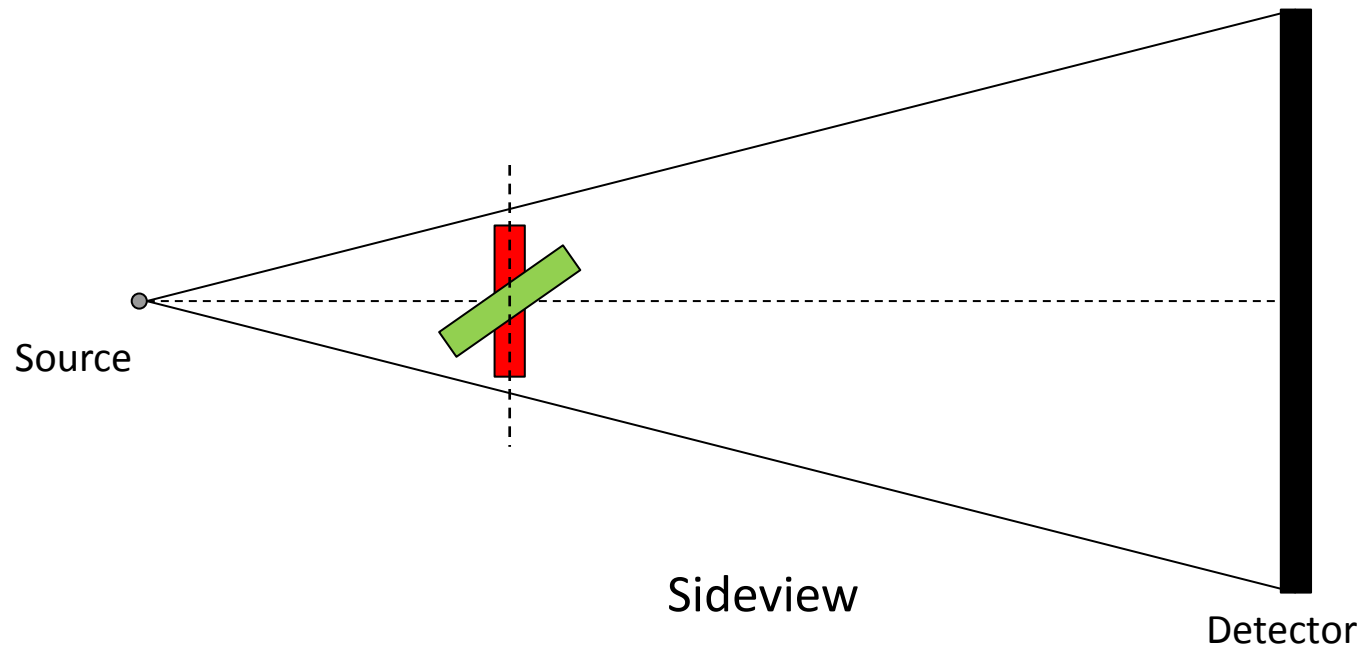


Voxel size: $105,7 \mu\text{m}^3$

Errors sources and good practice in CT scanning

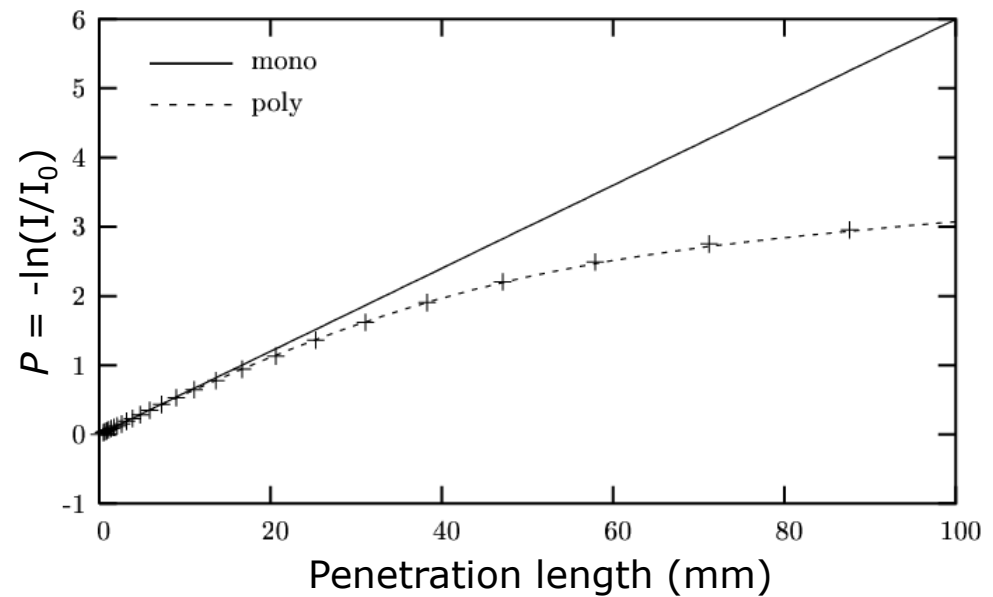
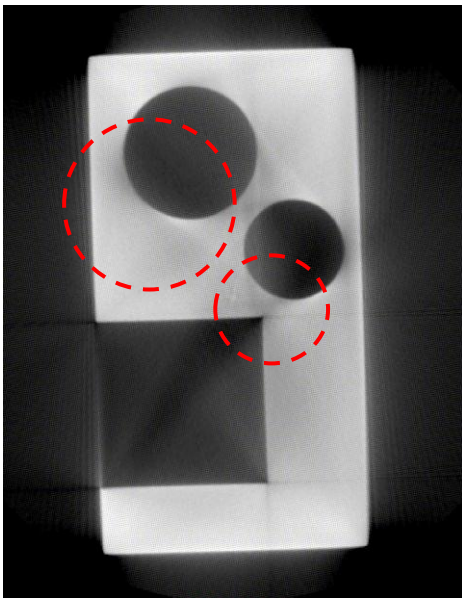
Good practice:

- Tilted position of the workpiece



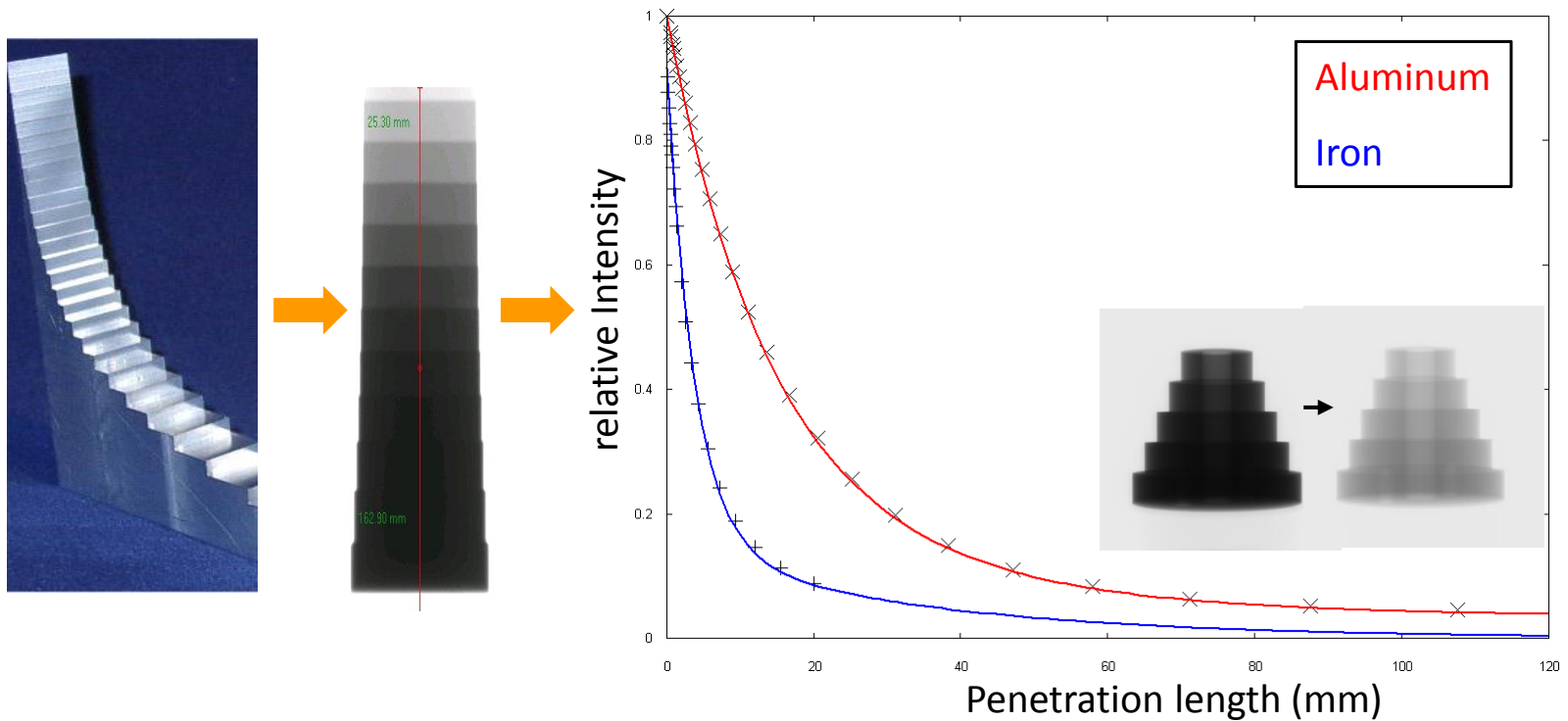
Errors sources and good practice in CT scanning

Beam-hardening:



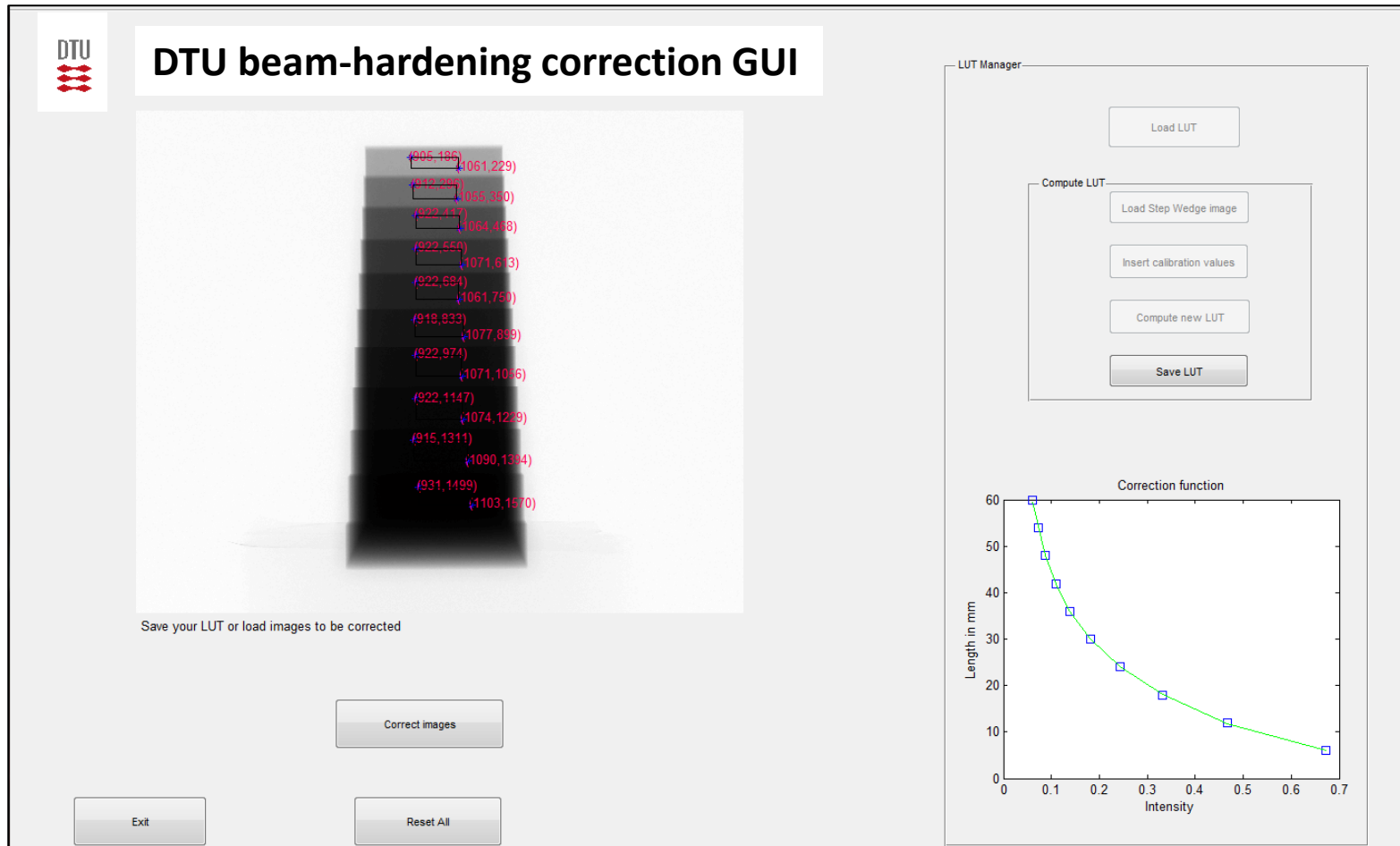
Errors sources and good practice in CT scanning

Beam-hardening correction:



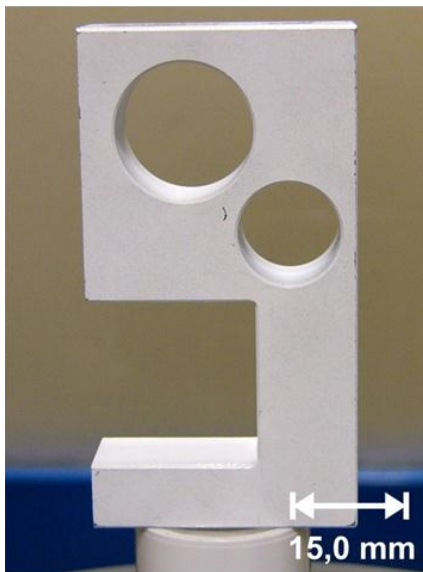
Step wedge → Radiography → Linerization of projections with inverse function

Errors sources and good practice in CT scanning

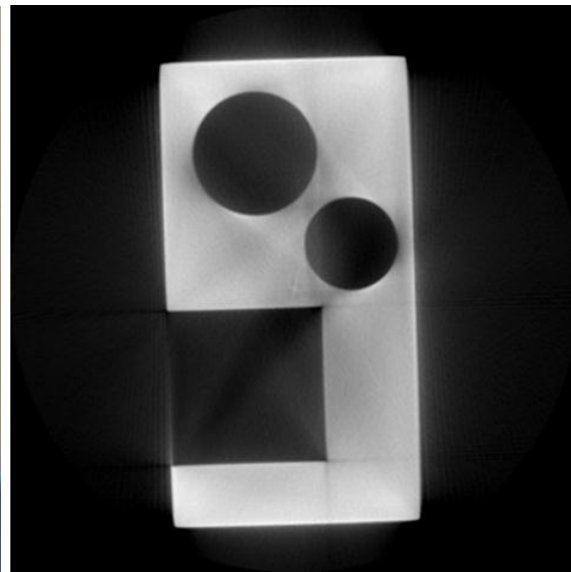


Errors sources and good practice in CT scanning

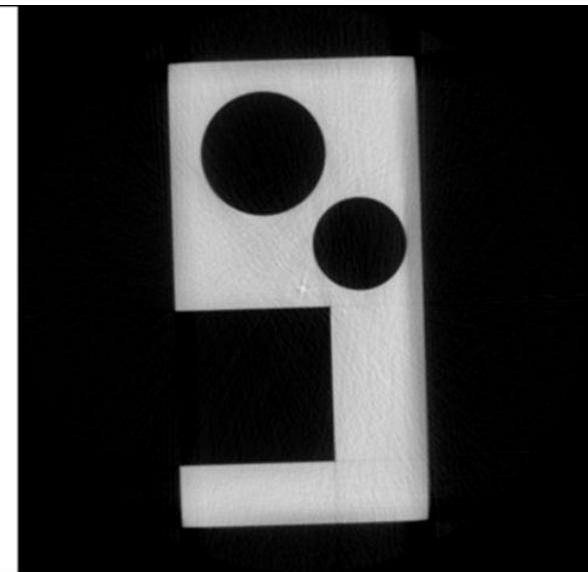
Beam-hardening correction:



Object (Al)



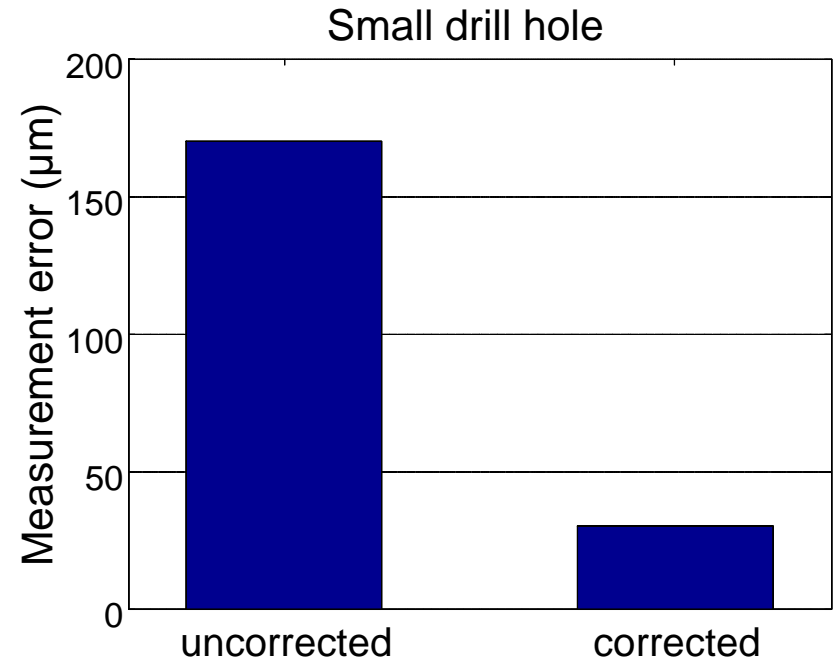
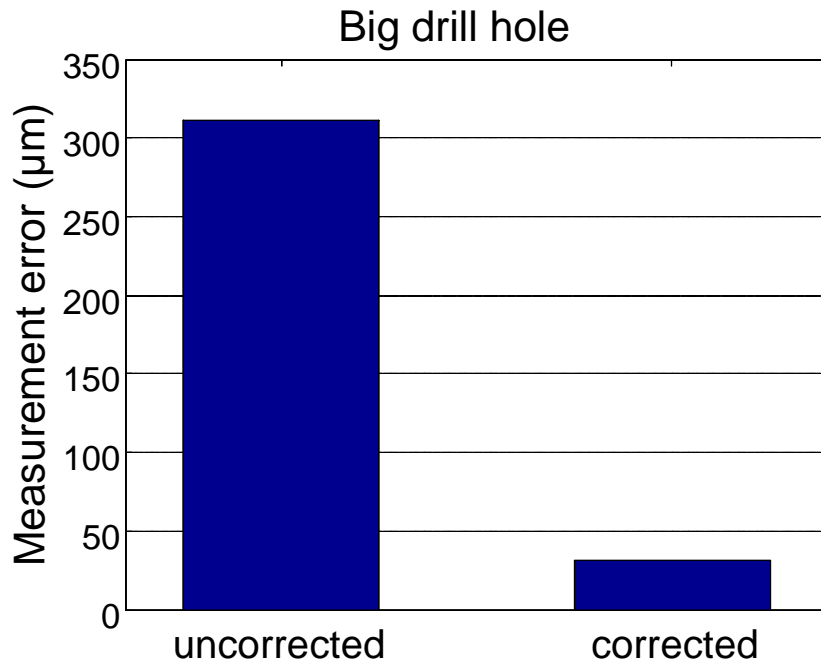
uncorrected



corrected

Errors sources and good practice in CT scanning

Beam-hardening correction:

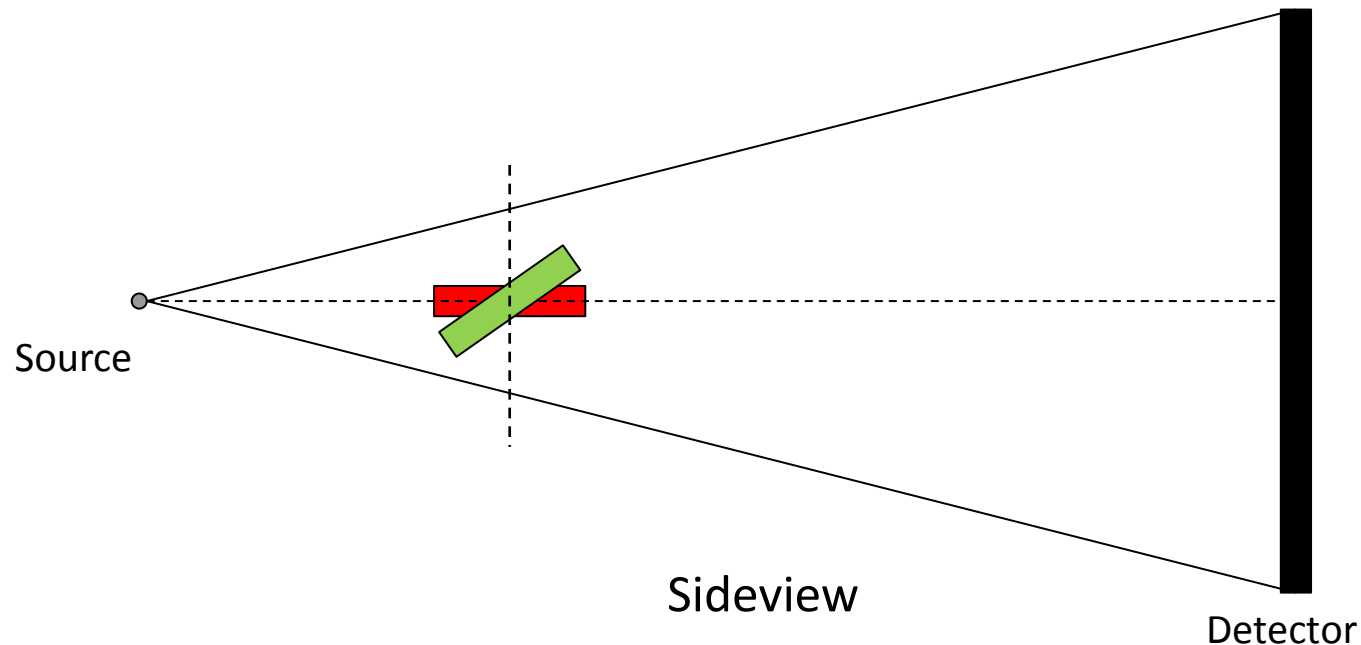


Voxel size: $(156,7 \times 156,7 \times 179,3) \mu\text{m}^3$

Errors sources and good practice in CT scanning

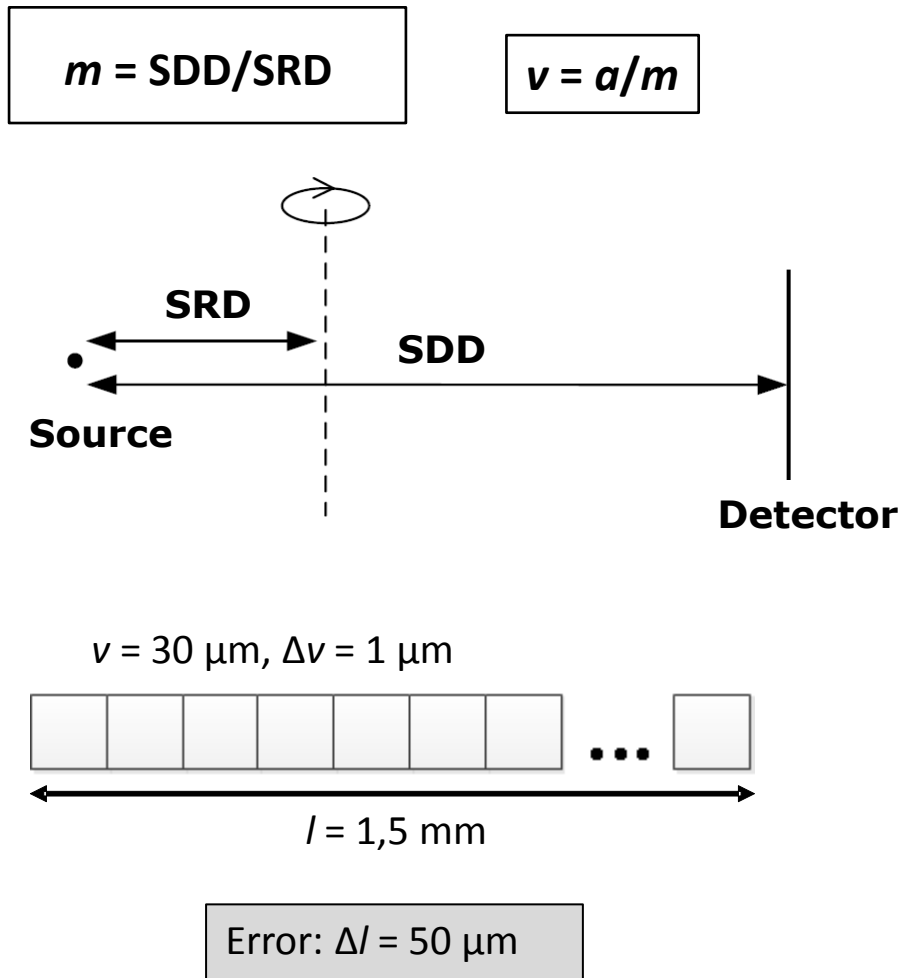
Good practice:

- Tilted position of the workpiece

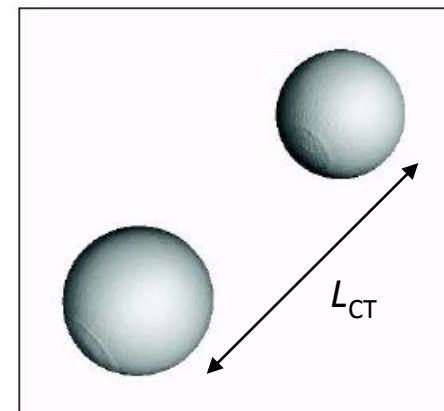


- Using a prefilter

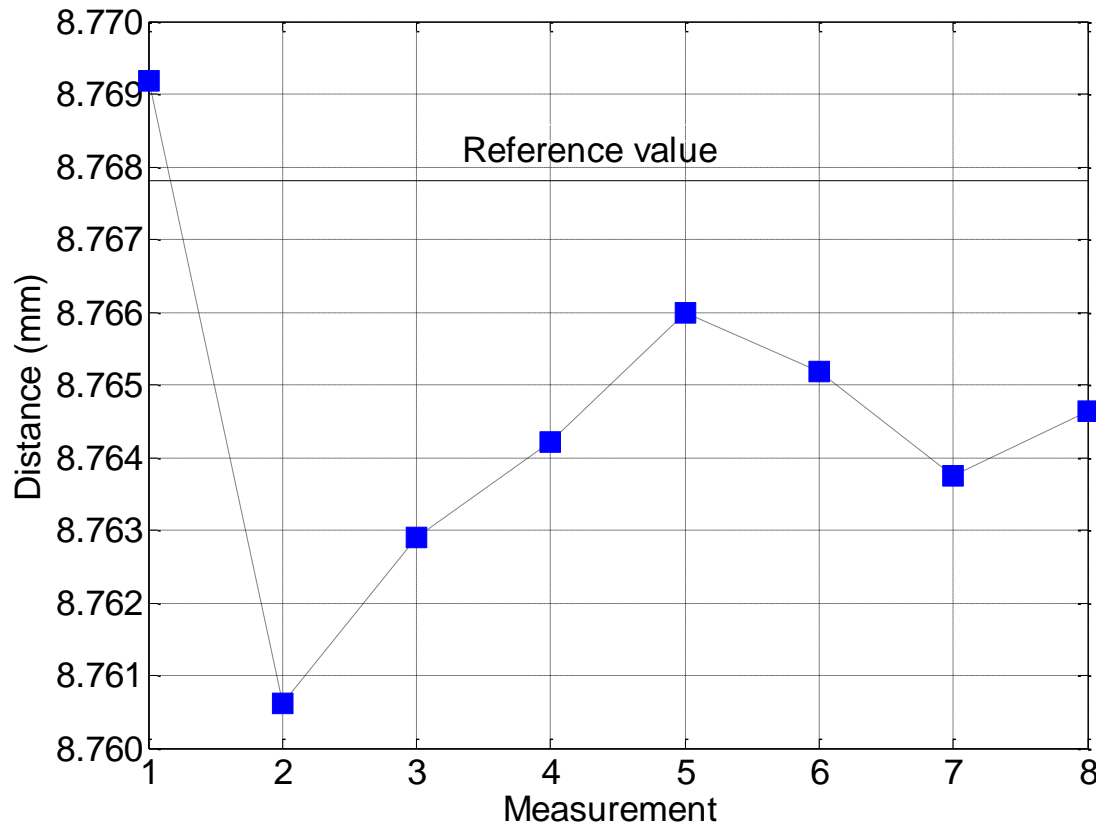
Errors sources and good practice in CT scanning



Calibrated length: 8,7678 mm



Errors sources and good practice in CT scanning



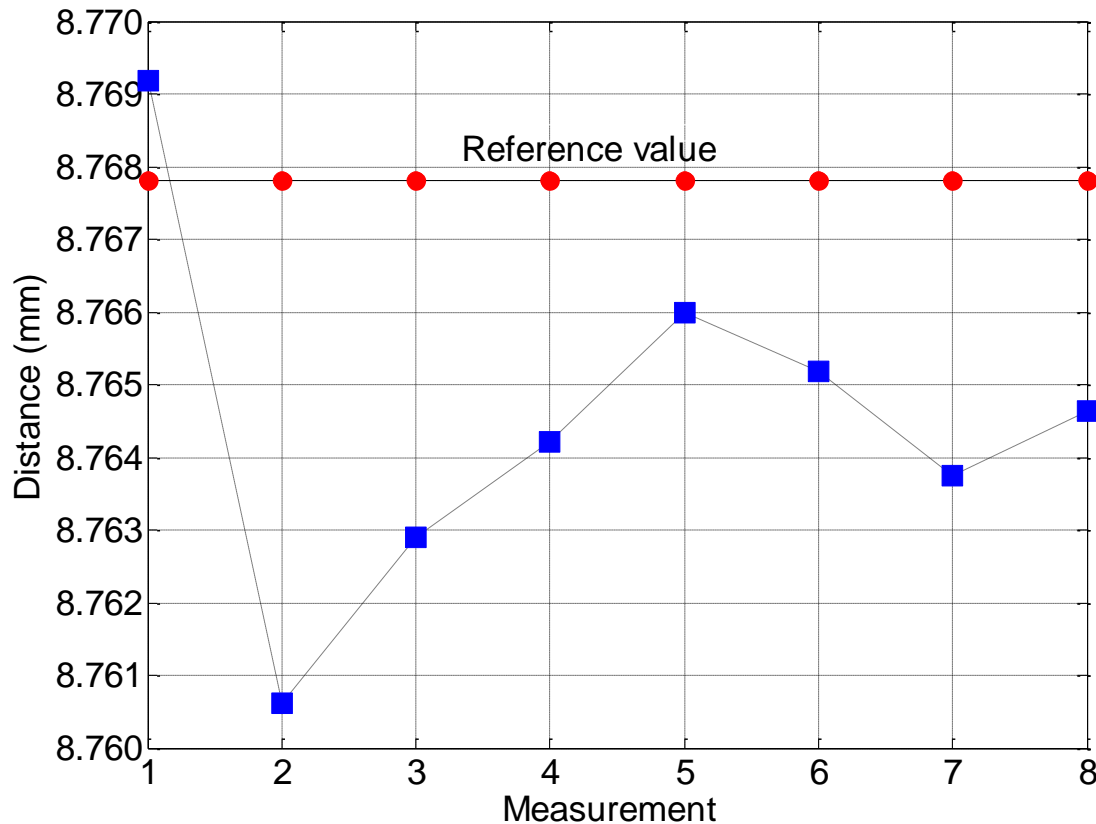
Variations are caused by
inaccuracies of the SRD
measurement (manipulator)

+

Focus drift during scanning
due to tube temperature
changes

superimposed

Errors sources and good practice in CT scanning



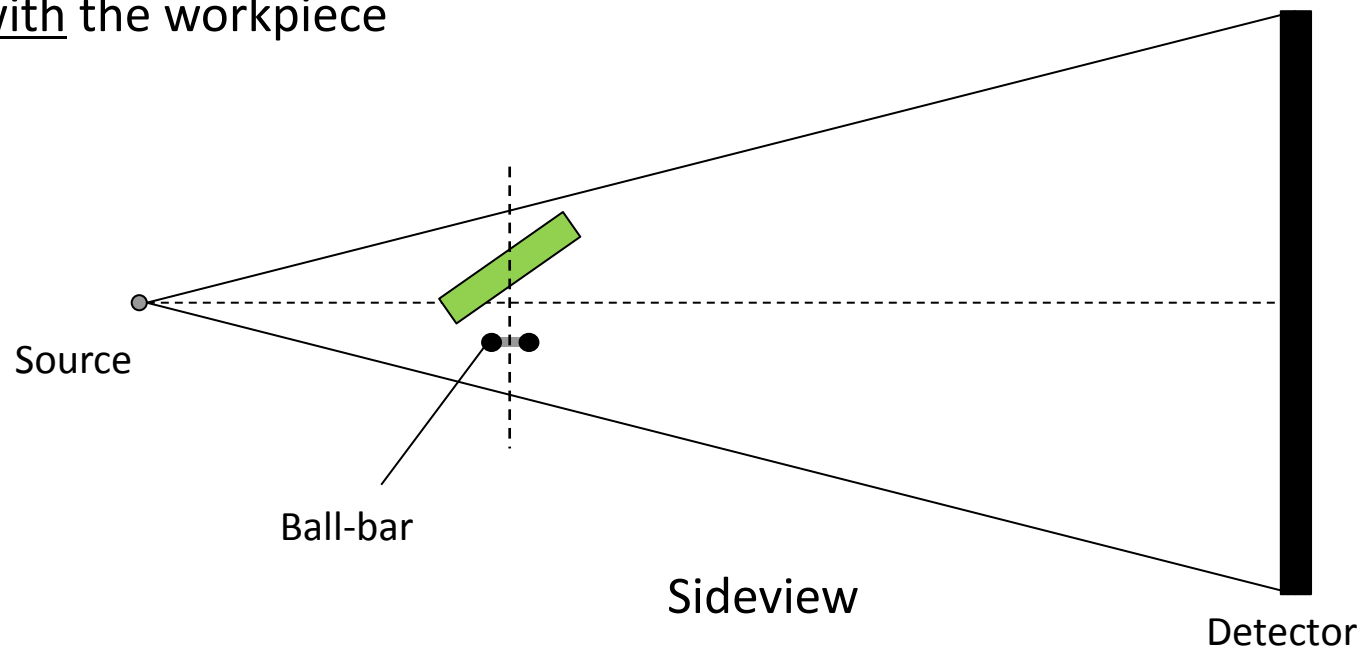
Voxel size rescaling:

$$\tilde{v} = v \cdot \frac{L_{\text{ref}}}{L_{\text{CT}}}$$

Errors sources and good practice in CT scanning

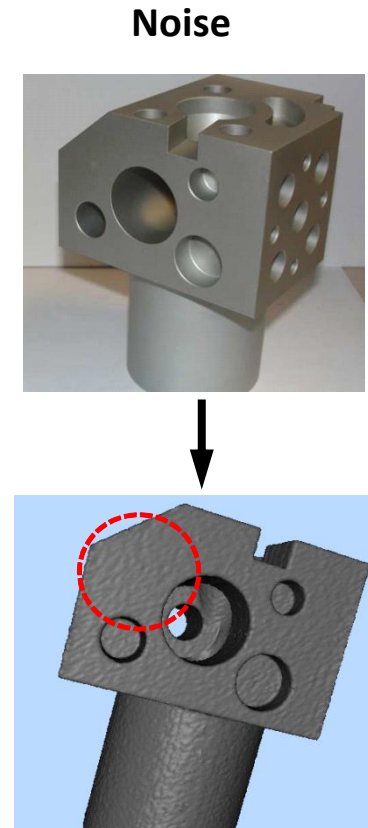
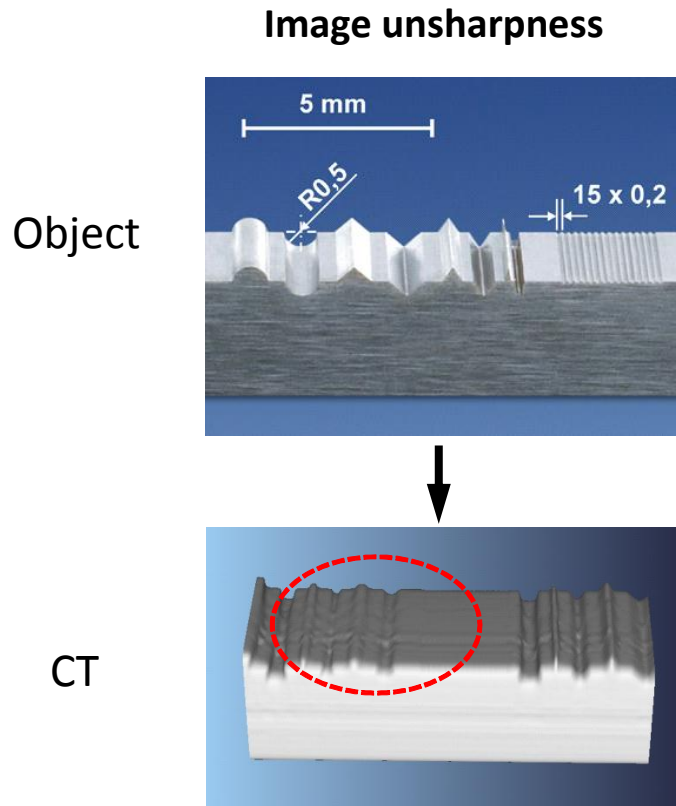
Good practice:

- In particular at high magnifications: Ball-bar must be scanned together with the workpiece



Focus drift differs from scan to scan!

Errors sources and good practice in CT scanning

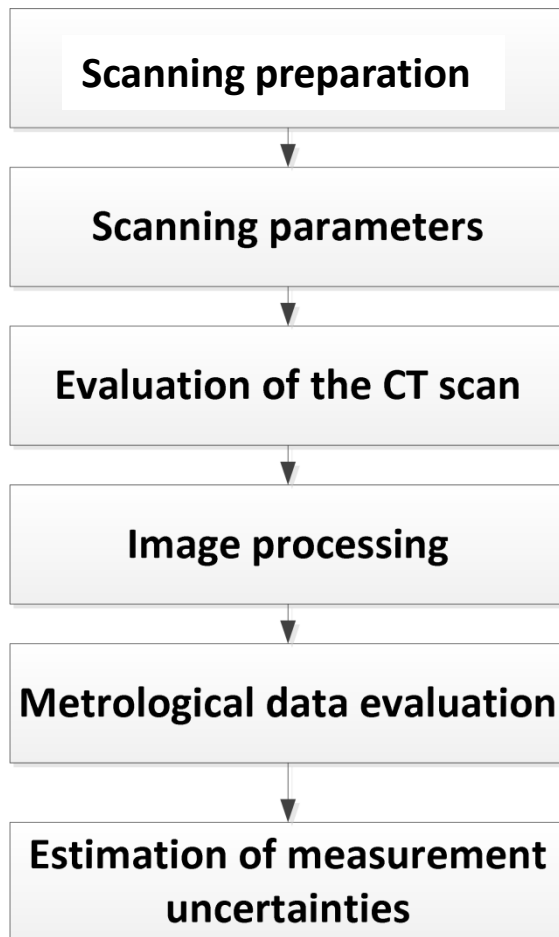


Depending on object, scanning parameters, system hard- and software

Conclusions and future works

- CT as a powerful and flexible tool in production metrology
- Variety of error sources and influence quantities in CT metrology
- Possibilities to reduce systematic errors (effects)
- Importance of a consistent procedure in CT scanning planning

Conclusions and future works



- Material, shape, penetration lengths
- Fixture, positioning, orientation
- Tube voltage, current, prefilter, detector settings
- Evaluation of detector images → histogram analysis
- Image quality (artefacts, sharpness, noise)
- Voxel histogram analysis, threshold tests
- Surface quality inspection
- Alignment
- Measurement strategy (elements, points, methods)
- Reference data available, repeated measurements

Invitation to Conference on

“Industrial Applications of CT Scanning – Possibilities & Challenges in the Manufacturing Industry”

June 12, 2012, 10:00-16:30

DTU, Building 101, meeting room 1

2800 Kgs. Lyngby, Denmark

Thank you very much!